Dynamics simulation and Research of Tribological Property of Involute Gear Meshing Based on Virtual Prototyping Technology

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***Abstract*—Based on virtual prototyping technology, and considering the influence of friction on impact load, the dynamics model of involute gear meshing is established by ADAMS. The simulation analysis is realized. The results of simulation analysis are basically in conformity with that of the theoretic calculation. The variation trend and reaction of the friction coefficient and relative sliding speed between gear teeth are researched. The results show that the simulation analysis and research of tribological property of involute gear meshing can be resolved by Virtual Prototyping Technology, which can lay the foundation for deeply studying the tribological properties of gear meshing. The method applied has good prospects in practical engineering application.**

Keywords- Involute gear; Virtual Prototyping Technology; Friction; Dynamics Simulation

I. INTRODUCTION

Virtual Prototyping Technology is a new technology which is applied to reform the product design and improve the product performance. The technology combines assemblies design with analysis technology in the process of product development, and the whole model of product is established in the computer. Under the actual work condition, the simulation analysis of model is realized and the performance of product is predicted [1-3]. Virtual Prototyping Technology plays an important role in the fields of aerospace, engineering and so on.

As a kind of basal mechanical transmission mode, gear transmissions are widely used in various machineries. Relying on the meshing between gears on the driveshaft and driven shaft, the power and motion are transmitted. Gear transmission has the advantage of compact structure, efficient transmission and a long life. The mechanical performance and work performance of the gear system have a great impact on the machinery system.

In this paper, the solid model of involute cylinder gear is established in Pro_E. Based on the virtual prototyping technology, considering the influence of friction on impact load, the dynamics model of involute gear system is established and the dynamics simulation is realized. Compared the simulation result with theoretical result, the model is proved to be feasible and correct. The variation trend and reaction of the friction coefficient and relative sliding speed between gear teeth are researched, which can lay the foundation for deeply studying the tribological properties of gear meshing.

II. DYNAMICS SIMULATION OF GEAR MESHING

A. Establishment and Import of Virtual Prototyping model

The methods of modeling for gear system are shown as following:

- A parametric model of involute gear is established by using Pro_E. Then using special interface Mechanism/Pro, the three-dimensional model can be transferred directly into ADAMS to avoid data loss. All controls and important markers can also be transferred to ADAMS. The method is introduced in detail in [4].
- Gears are assembled in Pro_E and the format of model is converted to IGES, stereolithography or Render. Then, the new model document is imported in ADAMS.
- The gear pair model is directly established in ADAMS.

ADAMS has strong ability in the dynamics simulation and postprocessor analysis. But its modeling ability is poor. To the complex mechanism, some lines and surfaces may be lost as the model is imported to ADAMS by using the second method. So the first method is applied to establish the gear system model and transfer the data. Fig. 1 shows the Virtual Prototyping model of the gear system.

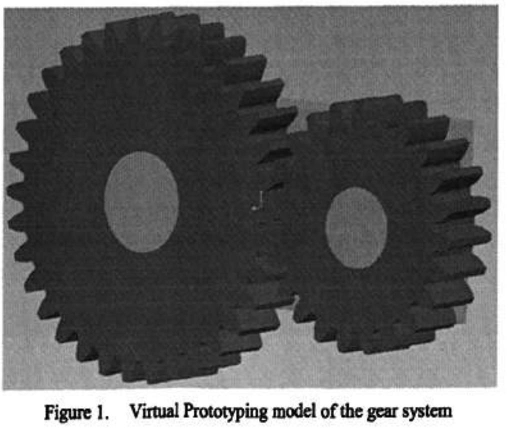

Figure 1. Virtual Prototyping model of the gear system

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B. Contact Impact Algorithm of Virtual Prototyping Technology

There are two types of contact forces. One is based on *Impact* function, the other is based on the *Restitution* function. The *Impact* function calculates the impact force on the basis of stiffness coefficient and damping coefficient and the *Restitution* function is on the basis of penalty function and coefficient of restitution. In this paper, the impact force is obtained by the *Impact* function in which the impact force is simulated as a nonlinear spring damper. Fig. 2 shows the contact impact model of ADAMS.

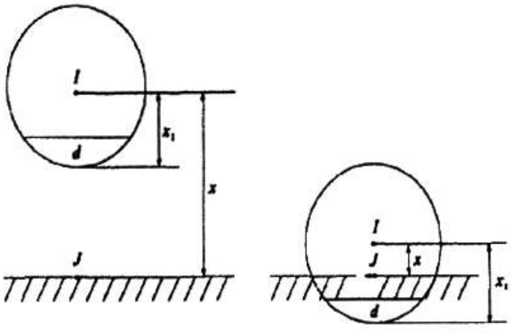

Figure 2. Contact impact model of ADAMS

Impact function can be given by

$$IMPACT=\begin{cases} MAX(0,k(x_1-x)^e-STEP(x,x_1-d,c_{max},x_1,0)\cdot\dot{x}) & x<x_1 \\ 0 & x\geq x_1 \end{cases} \quad (1)$$

where x is actual distance between the two objects (defined with a displacement function), $\dot{x}$ is time rate of change of the variable x, x_1 is trigger distance used to determine when the contact force turns on and off and should be specified as a real constant value, e is stiffness force exponent, c_{max} is the maximum value of damping coefficient, d is the damping ramp-up distance, and k is stiffness coefficient which can be obtained from *Hertz* theory.

According to *Hertz* theory, k is a variable which depends on the material and structural shape of the object. Relevant equations are shown as follows:

$$k=\frac{4}{3}R^{1/2}E \quad (2)$$

$$\frac{1}{R}=\frac{1}{R_1}+\frac{1}{R_2} \quad (3)$$

$$\frac{1}{E}=\frac{(1-\mu_1^2)}{E_1}+\frac{(1-\mu_2^2)}{E_2} \quad (4)$$

where R_1 and R_2 are the radiuses of the contact point on the two impact objects, μ_1 and μ_2 are the Poisson's ratios, E_1 and E_2 are the elastic modules.

C. Dynamics Simulation Results and Analysis

The parameters of the gear pair are listed in TABLE Ⅰ. Driving gear rotates at the constant angular velocity of 360 degree per second. In order to avoid a sudden change of the load, a step function *step*(*time*,0,0,0.2,150000) is applied to exert a torque on the driven gear gradually. Rotation constraints are laid on the shaft centers of driving gear and driven gear and the impact constraint is laid between the gear pair. Run a simulation for 0.5 seconds with 1200 steps.

TABLE I. PARAMETERS OF THE GEAR PAIR

Name	Symbol	Driving gear	Driven gear
modulus	*m*	2.5	2.5
Teeth number	*z*	23	34
Pressure angle	*n*	20°	20°
coefficient of addendum height of the gear	*ha*	1	1
Top-gap coefficient	*c*	0.25	0.25
Alternate coefficient	*x*	0	0
Breadth of tooth	*b*	20	20

Fig. 3 and Fig. 4 show the angular velocity of driven gear and meshing normal force.

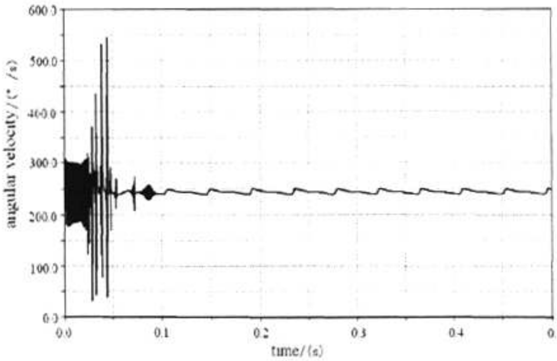

Figure 3. Angular velocity of driven gear

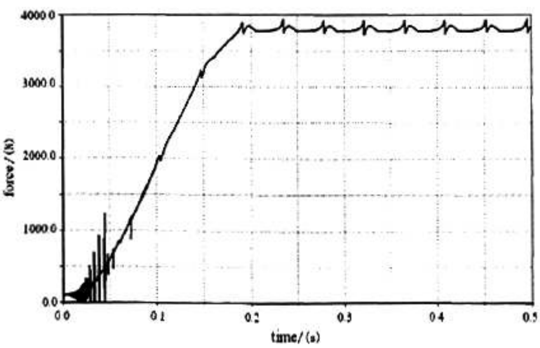

Figure 4. Meshing normal force

From the figure above, the velocity of driven gear is raised gradually at the beginning of run. The meshing force has some sudden changes because of the great impact between the gear pair. After 0.2 seconds, the velocity of the driven gear becomes smooth and enters a stable stage. The meshing force fluctuates around a certain average value, which is the result of meshing in and out of the gear pair in a certain cycle.

The theoretical values of the angular velocity of driven gear and meshing normal force are compared with the corresponding simulation values. The parametric values are listed in the TABLE II. The error is the absolute value of the ratio for the difference of simulation value and theoretical value and the theoretical value [5].

TABLE II. COMPARISON OF THE THEORETICAL VALUE AND SIMULATION VALUE

Comparison item	Angular velocity of driven gear (°/s)	Meshing normal force (N)
Theoretical value	243.53	3755.92
Simulation value	244.96	3800.65
Error (%)	0.59	1.19

From TABLE II, the error is reasonable in the sense of engineering, which can prove the correctness of the virtual prototyping model.

III. RESEARCH OF TRIBOLOGICAL PROPERTY

The friction force is resolved by the Column friction algorithm based on the relative sliding speed in the ADAMS. To the lubricated steel material, the static friction force reaches the maximum value at the speed of 0.1 millimeters per second. When the sliding speed is larger than 10 millimeters per second, there is only constant dynamic friction force between the meshing teeth. The dynamic friction coefficient is 0.05 and the static friction coefficient is 0.08. The simulation result of the friction coefficient and relative sliding speed are shown in the Fig. 5 and Fig. 6.

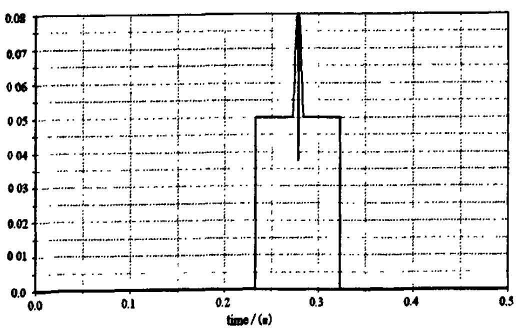

Figure 5. Friction coefficient of meshing teeth

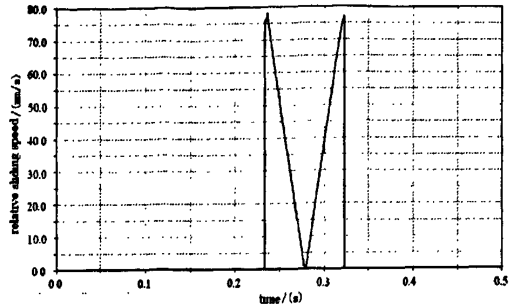

Figure 6. Relative sliding speed of meshing teeth

The meshing process of the gear pair is divided to two parts. From 0.233 seconds to 0.2787 seconds, two pairs of teeth are meshing from the site where the gears start touching to the pitch point. The relative sliding speed decreases gradually until the pitch point at which the meshing teeth remain static. The dynamic friction coefficient converts to the static friction coefficient and then to the maximum static friction coefficient. From 0.2787 seconds to 0.3229 seconds, the relative speed increase gradually until the teeth separate. The static friction coefficient converts to the dynamic friction coefficient. The analysis results of the friction coefficient and the relative sliding speed by ADAMS accord with the actual situation.

Based on the relationship between the friction coefficient and time and the relationship between the relative sliding speed and time, the relationship between the friction coefficient and the relative speed is obtained. The relationships in the two stages above are in good accordance. In the stage where the relative sliding speed decreases, the relationship between the two parameters is shown in Fig. 7. Here, only the relative sliding speed less 15 millimeters per second is shown.

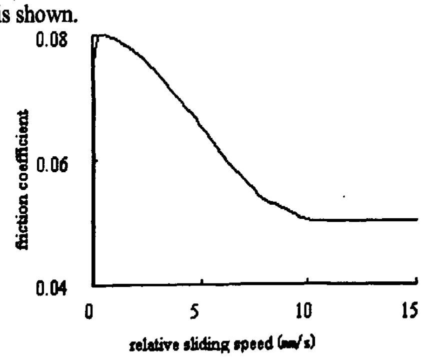

Figure 7. Relationship between relative sliding speed and friction coefficient

From the figure above, the relationship between the relative sliding speed and the friction coefficient accords with the Column friction theory of ADAMS. When the relative sliding speed is less 0.1 millimeters per second, there is only the static friction between the meshing teeth. When the relative speed is 0.1 millimeters per second, the static friction coefficient reaches the maximum value which is 0.08. When the relative sliding speed is larger than 10 millimeters per second, there is only the dynamic friction between the meshing teeth and the constant dynamic friction coefficient is 0.05.

IV. CONCLUSIONS

- The method, that Pro_E and ADAMS are combined to model and simulate dynamically, can play their full advantage and make up for the modeling weakness of ADAMS for the complex mechanisms and parts.
- Based on the virtual prototyping technology, simulation analysis of the gear meshing process is realized. The simulation result accords with theoretical result. The virtual prototyping technology can provide a accurate basis for the strength check, optimization design and the test of noise and vibration, which can get rid of the disadvantage of high cost and long period in the traditional design. The method can find good prospects in practical engineering application.
- The virtual prototyping model established can be applied to research the tribological property of all types of gear system. The relationship obtained between the friction coefficient and the relative sliding speed plays an important role for deeply researching the tribological dynamics property of the gear system.

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